

## LOW TEMPERATURE RESEARCH IN MICROGRAVITY

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The recent flight of the **Lambda** Point Experiment has demonstrated the potential for performing precise tests of fundamental theories using low temperature techniques in Earth orbit, NASA's **Microgravity** Science and Applications Division has established a program of successor experiments to investigate other aspects of condensed matter physics using the same low temperature flight facility. This paper will describe the new investigations that have been chosen for flight experiments, and those **selected** for ground-based studies that could lead to flight experiments later. The flight facility, which has now flown twice on the shuttle orbiter, will also be described. We **shall** also describe opportunities for investigators **to** apply for support of scientific studies that could gain significantly by **being** performed in a low gravity environment,

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The recent flight of the Lambda Point Experiment has demonstrated the potential for performing precise tests of fundamental science theories using low temperature techniques in Earth orbit. NASA's **Microgravity** Science and Applications Division has established a program of successor experiments to investigate other aspects of condensed matter physics using the same low temperature flight facility. This paper will describe the new investigations that have been chosen for flight experiments, and those selected for ground-based studies that could lead to flight experiments later. The flight facility, which has now flown twice on the shuttle orbiter, will also be described. We **shall** also describe opportunities for investigators to apply for support of scientific studies that could gain significantly by being performed in a low gravity environment.

## 1. Introduction

The Microgravity Science and Applications Division (**MSAD**) of NASA has supported research at low temperatures since the inception of the division. Recently MSAD decided to expand its program of low temperature research, so they released a NASA Research Announcement (NRA) offering opportunities for researchers to propose low temperature experiments in space. This paper will **decribe** the results of the selection of the proposals received in response to that announcement, giving brief descriptions of the chosen investigations. In addition, a description of the cryogenic flight facility that

provides the low temperature environment for the flight experiments will be presented. The paper will also discuss low temperature experiments that will not be flown in this facility. Finally, **future opportunities for investigators to take part in this program will be described.**

I must insert a disclaimer early in this paper. Although much of what I will present in this paper is based on my experience during a year's posting at NASA Headquarters in Washington, the observations and projections are my own, and do not reflect any commitment by NASA to continue to provide funds for any experiment or for any particular scientific discipline.

A brief **historical** note is appropriate for a presentation herein Eugene. While low temperature experiments in space were certainly conceived earlier, the **formal** start of the NASA low temperature program **occurred** right here in Eugene in 1975 when Prof. Donnelly organized a small meeting at **JPL's request**. 24 low temperature physicists met to discuss the questions at low temperature that would benefit from study in low gravity conditions. The first description of the Lambda Point Experiment was presented at this meeting by Prof. William Fairbank. Reviewing the material presented, it is obvious that the Stanford team had done their homework, because their descriptions of the optimum' size of the sample, the options for high resolution thermometers, and the effects of cosmic rays were implemented or observed in the **final** flight almost exactly as described in this 1975 meeting. Out of this meeting came a recommendation from the participants to NASA for inviting proposals for low temperature microgravity experiments.

To begin a program of flight experiments in low temperature physics, NASA needed to develop and demonstrate a cryogenic facility that could accommodate liquid helium

experiments. A flyable cryostat was built by the Ball Aerospace Corporation for JPL and a set of experiments to study the behavior of superfluid helium in a microgravity environment was designed by the JPL low temperature scientists. The cryostat incorporated the porous plug liquid-vapor separator that had been developed and tested in rocket flights by JPL and which flew successfully on the Infrared Astronomy Satellite in 1983. The experiments on the Superfluid Helium Experiment studied the bulk motions of superfluid helium, the temperature fluctuations in the bulk superfluid, and quantum surface waves in thick films of the superfluid. While some of the results of the Superfluid Helium Experiment were obscured by faulty wiring that introduced high levels of noise, the flight demonstrated that precision superfluid helium experiments could be flown in the reusable flight cryostat,

## **2. The Lambda Point Experiment**

Continuing the historical development of the program, of the several experiments that were originally supported for ground development of the science concepts, the Lambda Point Experiment (**LPE**), for which John Lips of Stanford University became the principal investigator, was the first to be approved for flight development in August 1986. This experiment has now been flown and the results from the flight will be described at this meeting by Prof. Lips. Because the LPE represents the vanguard of low temperature microgravity experiments, and so established the baseline for science value in this discipline and for techniques for implementation of such experiments, I shall describe briefly the experiment development from the viewpoint of the managing center JPL.

Two important technological developments were essential to the ability for the experiment to profit from the low gravity environment: the development of high resolution thermometers (Figure1), and the establishment of a high stability thermal

platform on which to perform the calorimetric measurements of the specific heat. The thermal platform is depicted in Figure 2, where the four stages of thermal isolation are shown between the 1.8 K cold flange and the calorimeter. With this platform and the high resolution thermometers, the apparatus demonstrated drift rates at the calorimeter below  $10^{-14}$  K/sec.

During the development of a NASA flight experiment, the normal procedure is to build a model of the instrument to use in testing to determine whether the instrument will survive launch vibration levels and will operate well in the environment expected on orbit. This engineering model is subjected to vibrations somewhat larger than expected on launch, and the electronics assemblies are operated in vacuum and over the range of temperatures that could be experienced in the shuttle and are exposed to rather high levels of electromagnetic radiation. Special facilities have been established at JPL in which to conduct such environmental tests.

For the Lambda Point Experiment, a **thermomechanical** model of the instrument was built and delivered to JPL for the tests; Figure 3 shows the cryostat and instrument mounted on the shake table at JPL. On shaking the instrument mounted in the flight cryostat, substantial heating was observed, heating sufficient to cause the superconductors in the high resolution thermometers to go through their transition into the normal state. Because the flux tubes for the thermometers (see Figure 1) were to be magnetized before launch and the trapped flux was to remain in the tubes throughout the flight, this heating through the superconducting transition was unacceptable. To avoid the heating,  $^3\text{He}$  exchange gas was placed in the inner guard vacuum space to provide cooling during launch, and then was removed once orbit was achieved. This procedure required the development and implementation of a sorption pump for removing the last traces of

exchange gas so the helium calorimeter would be adequately isolated from its surroundings during the specific heat measurements.

This was but one of several tests conducted at JPL that discovered a need for modifications to allow the instrument to operate well on the shuttle. In addition, the flight cryostat itself suffered a loss of vacuum integrity when a crack opened up on a structural weld on the helium tank. A major rework of the cryostat was undertaken by JPL, including a redesign of the attachments of the inner tank to the support straps that reduced the stress levels in those regions. The project team also resolved to reduce the risk of developing further leaks by adopting the procedure of cooling the system after integration of the instrument into the flight cryostat, and then keeping it cold through all the testing, through transporting to Kennedy Space Center, and through launch and operations of the mission. In all, the cryostat and instrument were maintained at helium temperatures for a continuous period of over 22 months.

### **3. The Microgravity Low Temperature Program**

Besides describing the present program, this paper has the objective of inviting your participation in the microgravity low temperature program. The procedure for obtaining application materials for responding to the next NASA Research Announcement for this discipline will be delineated later in the paper. At this point I will just point out that the next announcement is presently scheduled for October 1994. A large number of proposals in response to this announcement from the low temperature community will influence NASA to continue to expand its program in this area.

The Jet Propulsion Laboratory has been chosen by NASA's Microgravity Science and Applications Division to act as the lead center for low temperature microgravity

experiments. In that role, JPL provides communication between the low temperature science community and NASA Headquarters, as we are doing at this meeting. We also develop and maintain the low temperature cryogenic flight facility which I shall describe later. JPL manages the low temperature flight experiments in their development for flight, and provides integration and testing facilities for developmental and qualifying tests. Part of our role is to monitor the progress of the selected ground-based tasks and to provide the interface between those investigators and MSAD. Another part of the lead center role is to help MSAD prepare the research announcements; to this end, JPL has chosen to establish an advisory committee to inform us of the areas of current interest for microgravity studies. The willingness of scientists to serve on our advisory committee has contributed to the success of the recent announcement,

The response to the 1991 NASA Research Announcement (NRA) in Fundamental Science was 27 proposals in the low temperature area, 8 of which requested consideration as flight experiments. MSAD established a panel of scientific peers to review the proposals. The panel's recommendations were considered for programmatic aspects by the Science Branch of MSAD. This process led to the recommendation for funding of two investigations for flight definition, and ten others for ground-based studies. As well, another low temperature experiment was funded for ground-based study under the 1991 Fluids NRA. Brief descriptions of the successful proposals will be given hereto demonstrate the types of experiments presently being prepared for flight in microgravity. It is expected that this information will help other low temperature scientists determine what new research topics could be proposed for later NRAs.

#### 4. Description of the Flight Experiments

To be selected as a flight experiment, the science objectives of an investigation must be rated very highly by the peer review, and the benefit of experimenting in orbit must be clearly demonstrated. Another criterion weighed in the decision to accept a proposal is the relevance of the proposed work to NASA's objectives and mission. In evaluating the intrinsic merit of a proposal, factors such as the offerors capabilities and experience, the techniques and facilities available, and the qualifications of the proposed principal investigator are all considered. Also, the standing of the proposal amongst similar proposals available for evaluation, or its standing against the known state-of-the-art is weighed in the selection. And the reasonableness of the cost or its relationship to available funds also must be considered by the selectors.

With all these considerations, a peer review panel selected two low temperature experiments as being of sufficient merit to be chosen for flight definition: John Lipa's "A proposal to measure the effect of confinement on the specific heat of helium near the lambda point in microgravity," and Robert Duncan's "Critical dynamics in microgravity." In referring to these proposals by one individual's name I reflect the disposition of NASA to associate a project with the Principal Investigator (PI), since that person is always given the last word in decisions relating to the project's science goals and he/she is responsible for the progress of the project toward those goals. The two experiments listed above were proposed with three and two coinvestigators, respectively, but those individuals and the like coproposers for the ground-based investigations will remain in obscurity for the sake of brevity.

Prof. Lipa has proposed in this new experiment, now with the briefer name of the



Confined Helium Experiment (CHeX), to employ the growth of the correlation length near the phase transition to study the effects of confinement in a geometry large enough to be easily characterized. He will use the same apparatus that he prepared for the Lambda Point Experiment, with changes in the experimental cell, to measure the specific heat in a sample of helium that is mostly confined between closely spaced plates. The confinement is expected to shift the peak in the specific heat to a lower temperature and to reduce the peak height considerably. Figure 4 shows the expected behavior for a sample of helium having 80% of the helium confined in 100-micron gaps, while 20% is a bulk sample that provides a sharp peak at the bulk lambda point for a temperature calibration point. With this apparatus taking advantage of the low gravity conditions in orbit to approach very near to the transition temperature where the correlation length becomes macroscopic, Prof. Lipa expects to be able to resolve some of the questions remaining in confined systems regarding scaling, boundary conditions, and finite size effects. Figure 5 is a drawing of the calorimeter that his team at Stanford has designed for these measurements, with the 250 silicon plates being depicted oversize for clarity. This experiment is presently being prepared for a flight on the mission USMP-4 (the fourth United States Microgravity Payload mission) in November 1996.

The second of the proposals recommended for flight definition will investigate the lambda transition in a nonequilibrium condition. Dr. Duncan of Sandia National Laboratories proposes to impress a heat current on a sample of helium to observe the behavior of the transition region, the interface between the normal fluid and the superfluid, under such flow conditions. On Earth, the change of transition temperature with height in a sample of liquid helium caused by gravity allows the superfluid to overlay the normal fluid when the transition temperature is within the cell. Because the relative flow velocity between the two components  $\mathbf{w} = \mathbf{v}_s - \mathbf{v}_n$  is conjugate to the order

parameter, the superfluid density, impressed flows are expected to shift the transition and to change its nature from a second order transition to a first order transition that exhibits hysteresis.[1] Thus, the application of heat to a sample of helium can alter its transition properties, and can stabilize the interface between the two phases much like gravity does. This nonequilibrium situation promises a rich field of experimental investigation, which was reflected in the review panel's selection of three other similar studies for ground-based investigations in addition to this flight definition experiment.

Dr. Duncan proposes to substitute a special experimental cell for the calorimeter on the LPE/CHeX thermal platform so he can measure the thermal conductivity near the normal fluid-superfluid interface as he varies the magnitude and direction of the applied heat flow. Figure 6 shows a thermal model he has used to calculate the distortion of isotherms in the sample cell when heat flows through the cell and high conductivity temperature probes are fixed at different positions in the cell wall. He will describe such modeling and the application of the results to the design of his experimental cell in another paper at this conference. Dr. Duncan has also developed a conceptual model of the experimental cell incorporating a pressure transducer/controller that would allow measurements at different densities to test universality, and that would also permit isothermal quenches through the transition. Dr. Duncan's experiment, now being identified by the acronym DYNAMX, is just beginning its development for flight, preparing for the Science Concept Review in late 1994. If development of the flight experiment proceeds according to plan, DYNAMX will fly in October 1998 aboard the shuttle mission USMP-6.

## 5. The Ground-based Investigations

This paper does not allow sufficient room to provide elaborate detail concerning each of the eleven ground-based investigations in the low temperature program. After all, each of these were described by approximately ten pages of text in the proposals that justified their funding. However, a few lines representing the highlights of the tasks will be presented for each study, hoping that none of them will be slighted to any great degree by such a brief portrayal.

As stated above, three studies were selected for ground-based investigation in the area of **nonequilibrium** phase transition studies. **Guenter Ahlers** is examining the effect of an applied heat flow on the thermal conductivity near the transition. He is already acquiring data on such effects that are being reported at this conference. Nonlinear thermal conductivities are expected very near to the transition with an applied heat flow, [2] but observing these effects on Earth where the approach to the transition is limited by gravity may not be possible.

**Talso Chui** has proposed an alternative way of generating  $w = v_s - v_n$ , namely to set up persistent currents in a **toroidal** sample of helium. Because such a state of the helium is not being driven as in the heat flow experiments, but is rather in a **metastable** state, this arrangement may represent new physics for the transition in a condition of flow, and may help to delineate the processes acting in the altering of the transition properties. Dr. Chui will measure the specific heat near the lambda transition as a function of the rate of flow, measuring the shift of the transition temperature and looking for the change in the transition from second order to first order.

Dr. Ulf **Israelsson** will try yet another technique for observing the effects of flow on the phase transition. He will apply a large magnetic field gradient to the helium sample to generate body forces that counteract gravity, thereby reducing the gravity-induced nonuniformities in the helium by a factor 100. In this way he expects to approach the transition close enough to observe and measure the nonlinear thermal conductivities expected in the heat flow in that temperature regime. Because he is applying a large magnetic field to the helium sample, he will not be able to use the paramagnetic salt high resolution thermometers as developed by Lipa's group at Stanford, so he will use instead the melting curve thermometer as employed by **Ahlers'** group at the University of California at Santa Barbara. A description of this experiment is being presented at this conference in another paper.

Leaving the studies of **nonequilibrium** effects at the lambda transition, two of the ground-based investigations will examine the liquid-vapor critical point in  $^3\text{He}$ . Horst Meyer is measuring equilibration rates near the critical point to determine the feasibility of performing high resolution measurements close to the transition. Experiment durations in orbit are limited, so equilibration after an adjustment of the temperature is important to allowing the microgravity investigation to approach more closely to the transition. Prof. Meyer and his associate Dr. Fang **Zhong** are measuring how fast the density of a sample of  $^3\text{He}$  adjusts as the temperature is stepped toward the transition. Fitting the final portion of the density relaxation to an exponential, they find that the relaxation times increase as a power law of the reduced temperature as the transition is approached, but at the smallest reduced temperatures ( $<10^{-4}$ ) the relaxation time becomes constant. They interpret this leveling as an effect caused by gravity-driven currents, and speculate that in low gravity the relaxation time will continue to diverge,

Marty Barmatz is planning to perform precise measurements near the  $^3\text{He}$  liquid-vapor critical point of several properties of the fluid to determine the exponents  $\alpha$  and  $\gamma$  *alpha, gamma* for the asymptotic behaviors of the specific heat and viscosity, respectively. The primary measurements will be the velocity and attenuation of first sound in resonators. As shown in the Figure 7, two resonators for first sound are included in the design of the experiment cell. One is toroidal for the lower frequencies to provide a long path length. The other is a short path for the megahertz frequencies. The cell will allow the measurement of density, pressure and temperature to high precision, so universality of the results can be tested with the measurements.

Three experiments have proposed to observe the behavior of an isolated drop of helium in microgravity. Two of these are interested in the hydrodynamics of the superfluid, looking at the motions induced when the helium is spun up. Humphrey Maris will levitate the drop with magnetic fields to study the hydrodynamics of the quantum fluids. He has laid out a series of steps to develop a flight experiment that should permit the study of larger, more symmetric drops, Russell Donnelly may employ electrostatic control of the drop, or he may use a hybrid of electric and magnetic forces to position and spin the drop. Prof. Donnelly will study the nucleation and decay of vortex lines in the superfluid drop, with and without impurities added to the drop to serve as nucleation sites. Both of these experiments may require subkelvin temperatures to study the drop well isolated from its surroundings.

The third drop experiment is proposed by Woods Halley to measure the condensate fraction existing in the superfluid drop. By injecting pulses of low-energy helium atoms at the drop, and measuring the energies of the atoms ejected from the opposite side, he expects to observe a signature of the condensate fraction. Prof. Halley just hosted a satellite conference at the University of Minnesota where the feasibility of such

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measurements was thoroughly discussed; he also is presenting an invited paper at this meeting on this subject. Techniques for performing this experiment are also being explored by the Minnesota group.

Charles Elbaum is planning to study the kinetics and thermodynamics involved with the growth of solid crystals from **superfluid** helium. At certain regions of the state parameters such growth proceeds with zero latent heat, so heat exchange at the liquid-solid interface does not limit growth rates. Waves have been observed at the interface that move very rapidly along a surface. Also, a roughening transition is known to occur at low temperatures, greatly affecting the growth rates. The morphology and dynamics are expected to change when the crystal is grown in a low gravity environment,

Graham Ross is developing a computational fluid dynamics model of the two-fluid hydrodynamics of helium and is testing that model with measurements of slosh amplitudes and the damping of the fluid motions above and below the lambda point. He has already begun making such measurements in Earth's gravity and expects to extend them to the mini-g environment of NASA's KC-135 aircraft soon.

Finally, two theoretical studies were selected from the 1991 NRA in support of the low temperature program. Prof. Richard **Ferrell** will study the critical dynamics of helium near the lambda transition, focusing on the proper choice of boundary conditions for helium near walls and on the effects of impressed heat flows on the lambda transition, Prof. Efstratios **Manousakis** will apply Monte Carlo methods to calculations that will investigate finite size effects in helium samples of restricted dimensions.

## **6. The Satellite Test of the Equivalence Principle (STEP)**

The STEP experiment is a low temperature relativity experiment that has been supported by MSAD for many years. Francis Everitt and Paul Worden of Stanford University are intending to perform a test in Earth orbit of the equivalence of a body's gravitational and inertial masses with resolution of  $10^{-17}$ . Such a test would be an improvement by six orders of magnitude on the best previous test of this principle that is so fundamental to the theory of relativity. Since STEP requires the satellite to be drag-free at the  $10^{-11}$  g level, it cannot be performed on the Shuttle but requires a free-flyer.

To perform such high resolution comparisons of gravitational accelerations, the STEP experiment will employ superconducting differential accelerometers where masses of differing composition are placed in free fall in Earth orbit, and the measurements of displacement will test whether all masses respond to gravity similarly; a design for such a differential accelerometer is depicted in Figure 8. The masses are levitated on superconducting magnetic bearings that allow motion along one axis with no resistance. The position detector coils near the ends of the levitated masses contain currents so that motion of the superconductor-coated mass will change the flow of current, and this current change will be detected by low-noise superconducting instruments called SQUIDS. The electrostatic positioning electrodes keep the masses centered on the sensitive axis. STEP is in a preproject study phase, with a new start expected in 1996 and launch projected to occur in 1999 or 2000.

## **7. JPL's Reusable Cryogenic Flight Facility**

The JPL flight cryostat was mentioned in the Introduction as an element required for NASA to establish a program of low temperature experiments in orbit. The JPL facility has already flown twice, in 1985 for the Superfluid Helium Experiment and in 1992 for

the Lambda Point Experiment. It is now slated for two more flights: in 1996 for JPL's Confined Helium Experiment and in 1998 for Duncan's Critical Dynamics in Microgravity Experiment. For reference for future proposers to research announcements, the properties of this facility will be described here.

The 100-liter liquid helium bath provides nominally a 10-day experimentation period on orbit. Including the ground-hold time prior to launch, the facility lasted 12 days for the flight of the Lambda Point Experiment, and JPL is now making minor modifications to the fill procedure and to radiation baffling to improve the lifetime. The temperature of the bath on orbit is somewhat below 1.8 Kelvin, with a temperature stability near  $10^{-3}$  K; this stability could be improved if active control were applied using a heater in the bath. The facility provides the experiment with mechanical, electrical, data, and communications interfaces to the Shuttle systems. The experiment volume consists of a cylinder 21 cm in diameter and 91 cm long that extends directly into the liquid helium bath; the instrument is expected to provide its own isolation vacuum space and heaters or coolers if temperatures other than those of the helium bath are required.

The whole facility is surrounded by a high-permeability magnetic shield that reduces by a factor of 50 changes in the ambient magnetic field. Figure 9 shows the facility with its surrounding magnetic shield mounted on a mock-up of the Multipurpose Experiment Support Structure that supports the experiment in the Shuttle bay. In the foreground of the photograph are several boxes of electronics attached to the side of the structure, plus the Vacuum Maintenance Assembly on top of it. The Vacuum Maintenance Assembly keeps the helium bath below the lambda transition during the period on the launchpad after the Shuttle bay doors are closed until 30 minutes prior to the nominal launch time; this period is usually about three days, but could be extended by launch delays.



## 8. Ways to Participate in NASA's Low Temperature Program

MSAD is planning to release NASA Research Announcements for the low temperature area at regular intervals, essentially annually. While the 1991 NRA was titled as a Fundamental Science NRA, future opportunities for the low temperature community will likely be included with a Fluids NRA release. Normally 10,000-15,000 copies of an NRA are sent to a mailing list derived from rosters of the American Physical Society and from lists of conference attendees. However, if an individual is not receiving these announcements and wishes to begin receiving them, she or he should make an effort to contact JPL to be placed on the mailing list. In fact, JPL produces a Low Temperature Microgravity Newsletter that is presently being mailed to a number of scientists. By contacting JPL by any means listed below you can be added to the mailing list for the newsletter so you will be informed of the dates of workshops and expected NRA releases, plus other developments in the low temperature program,

The various means to contact JPL are as follows:

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As stated above, the next NRA to which the low temperature community can respond will be released in October 1994 as a Fluids announcement. To prepare for the low temperature **portion** of the NRA, a low temperature workshop is being planned for early January, possibly January 9-11, 1994, in the Washington, D.C. area. Exact dates and location for the workshop will be available soon and will be published in the next issue of the newsletter.

Other activities in which individuals could participate to support the low temperature **microgravity** program include the workshops, **advisory** committees, and proposal review panels. JPL determines for MSAD the subject areas to include in a particular NRA from presentations by workshop attendees, and from the advice of members of the JPL Low Temperature Science Steering Group. Thus, participation at the workshops and on the steering group is a valuable service to JPL and NASA. These inputs allow JPL and MSAD to assess the areas of particular interest to the science community at the time of release of an announcement. However, if the subject an investigator would propose is not included in an announcement, that should not discourage the proposal because the NRAs usually include a blanket statement seeking proposals for "innovative fundamental research beyond those specific areas described." The proposer only need convince the review panelists and the MSAD Science Branch that the experiment requires low temperatures and is germane to the MSAD objective of conducting research in the **micrgravity** environment to improve the understanding of fundamental physics. Finally, a panel of scientific peers is set up by MSAD to review the submitted proposals for their scientific merit and relevance to the MSAD program; an individual can also support the program by serving on such a review panel.

## **9. Other JPL Activities Relating to the Low Temperature Community**

JPL is presently establishing a low temperature laboratory that will include several high thermal stability platforms equipped with high resolution thermometers. Over 5000 square feet of area will be divided for flight experiment preparation and for ground-based experimentation. This laboratory is planned for occupation in April 1994.

The reason this laboratory relates to the low temperature community is that JPL intends to formulate a Visiting Guest Investigator program to use some of these facilities. It is imagined that visitors will stay at JPL for about three months, employing the high resolution platforms to work on problems of mutual interest to the visitor and to JPL. This work could pursue either a scientific subject or a technical development. It is anticipated that JPL would supply funds to cover the travel expenses and living expenses, but not salary for the visitors.

## **10. Summary**

This paper has described a NASA-supported broad-based program in low temperature **microgravity** research. NASA is supplying over \$1.3 millions in 1993 for the **ground-**based investigations alone. If the low temperature community demonstrates a high level of interest in the NASA program by responding in large numbers to the October 1994 NASA Research Announcement, the Microgravity Science and Applications Division of NASA has expressed its intention to further expand its support in this area, possibly doubling the number of investigations selected. This intention demonstrates an increased opportunity for investigators to join in a program that develops benchmark experiments of wide scientific interest.

## 11. References

1. A. Onuki, J. Low Temp. Phys. 50,433 (1983); J. Low Temp. Phys. 55,409 (1984).
2. V. Dohm, Proceedings of the Sixth Oregon Conf. on Low Temp. Phys., p. 92, unpublished.

## 12. Figure Captions

Figure 1 High Resolution Thermometer (HRT). A magnetic field trapped in the superconducting niobium flux tube tends to align the magnetic moments in the paramagnetic salt pill. Changes in temperature change the amount of alignment, causing the magnetic field in the pick-up loop to vary. The resulting change in current in the pick-up loop is sensed by the SQUID device. The heat switch is used to destroy trapped currents in the pick-up loop.

Figure 2 High stability platform developed for the Lambda Point Experiment. The drawing shows the three stages of thermal isolation, the thermal shield and the high resolution thermometers that produce drift rates for the temperature of the calorimeter as low as  $10^{-14}$  K/sec. The superconducting shield and the solenoid allow the operation of the HRTs at high sensitivity.

Figure 3 Photograph of the JPL reusable cryogenic facility with the engineering model of the Lambda Point Experiment being tested on a shaker facility in JPL's Environmental Testing Laboratory.

Figure 4 Calculated results of specific heat measurements for the Confined Helium Experiment (CHeX). For the calculation, 80% of the helium is assumed to be confined to 100  $\mu\text{m}$  wide gaps, while the other 20% is unconfined to give the sharp bulk peak shown.

Figure 5 Drawing of the CHeX calorimeter. The spacing of the silicon wafers has been exaggerated for clarity. Dimensions shown are in inches. Note that both the confined regions between the wafers and the bulk region beyond the wafers are depicted.

Figure 6 Model used for DYNAMX for calculating the perturbation of the thermal profile in a thermal conductivity cell by the high conductivity aluminum temperature probes. Several probe positions, varying both in penetration depth and in location along the wall, were modeled to find the position where they least disturb the isothermal contours when the helium is very close to the lambda point,

Figure 7 Schematic of an integrated critical point measurement cell for Barmatz' 3He liquid-vapor critical point experiment. The cell contains components for measuring low and high frequency sound velocity and attenuation, plus the sample temperature, density, and pressure. The specific heat will be determined by applying heat pulses and measuring the resulting temperature rise. (1) high resolution thermometer, (2) germanium resistance thermometer, (3) density measuring capacitor, (4) high frequency sound resonator, (5) superconductive pressure sensor, (6) low frequency annular sound resonator, (7) pressurizing flexible diaphragm, (8) pressurizing actuator.

Figure 8 Differential accelerometer for the STEP experiment, See text for details of operation.

Figure 9 Photograph of the JPL reusable cryogenic facility mounted on a mock-up of the support structure for the Space Shuttle bay.



















